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Uniting geospatial assessment of neighborhood urban tree canopy with plan and ordinance evaluation for environmental justice☆

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ABSTRACT

Trees are not evenly distributed across urbanized areas and there is evidence that Black, Hispanic, and low-income residents have lower proximal tree canopy coverage. The complex interplay between social policy and the built/physical environment contributes to these outcomes, but much of the research on environmental justice focuses on either producing evidence of inequity or assessing policy to determine its effect on the physical environment. This paper attempts to unite those two approaches by 1) measuring the urban tree canopy (UTC) at a scale that reflects local socio-political decision making and 2) assessing how the local policy documents regulating UTC acknowledge and attempt to remediate disparity. A maximum likelihood supervised classification of 1-m resolution imagery for a purposive sample of twelve historically racially segregated neighborhoods in two North Carolina cities estimated UTC at the block level. Using a spatial autoregressive model, we found a statistically significant negative association between UTC coverage, percentage of non-White population, the presence of nonresidential zoning, and percentage of parcel within the right-of-way. Content analysis found the municipal comprehensive plans and development management ordinances lack city-wide canopy coverage goals, do not utilize neighborhood geographies to target action and evaluation, and do not account for, or attempt to reduce, the potential inequitable distribution of urban trees. Existing policies could further contribute to disparate UTC outcomes by allowing neighborhoods to create their own UTC coverage standards and by crafting ordinances with variable standards for neighborhoods with non-residential zones. As a result, communities unable to counteract intensive zoning and/or advocate for enhanced tree canopy provisions are at a disadvantage in the remediation of UTC disparities. These findings highlight the need for analytical approaches that integrate the identification of disparities with the evaluation of present-day policy frameworks that may perpetuate and/or exacerbate inequitable outcomes.

1. Introduction

The intentional preservation or placement of trees has a long term effect on urban tree canopy (the upper layer of trees viewable from above) and, by extension, ecosystem health, human social, economic, and psychological well-being, and community valuation (Nilsson et al., 2001; USDA Forest Service, 2017). Shading from trees can counteract increased temperature, reduce respiratory difficulty, and decrease the probability of heat-stroke, exhaustion, and heat-related mortality (Kovats and Hajat, 2008; Lo and Quattrochi, 2003). There is evidence that vegetation provides psychological and monetary benefits Resident well-being and satisfaction with their neighborhood was positively correlated with window-viewable vegetation (Kaplan, 2001) and canopy coverage affects neighborhood perception, and consequently, its valuation (Schwarz et al., 2015). The lack of vegetation and hardscapes made of metal, concrete, asphalt, and other non-natural materials are associated with undesirability and lower residential property values (Anderson and Cordell, 1988).

Significant differences in the quality of the built environment at the neighborhood level have been documented for low income neighborhoods and communities of color including the proximity to potentially harmful, locally unwanted land uses (Arnold, 2007; Bullard et al., 2007; Mohai et al., 2009; Morello-Frosch et al., 2001), the disproportionate disintegration of majority-minority communities via highway expansions (Chi, 2011), and the systematic denial of basic amenities like water, sewer lines, and infrastructure improvements (Heaney et al., 2011; Wilson et al., 2008). While a substantial portion of the literature on environmental inequity focused on low income households' and

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racial/ethnic minorities' communities' disproportionate proximity or exposure to hazards, noxious uses, or otherwise negative environmental attributes (Szasz and Meuser, 1997), this study joins a growing body of literature regarding the absence of positive environmental features such as open, green space and parks (Abercrombie et al., 2008; Dahmann et al., 2010; Dai, 2011; García and White, 2006; Jennings et al., 2012; Sister et al., 2009; Wolch et al., 2014). Existing literature suggests UTC coverage is variable on both large and small scale geographies (e.g. between cities across the U.S. and also within cities), and this variation can, at least in part, be attributed to residential segregation by sociodemographic characteristics such as income and race (Gee and Payne-Sturges, 2004; Trounstine, 2016). Building on previous studies that focus on unequal distribution of urban trees and other natural resources, we include a content analysis of the policy documents guiding development to examine how current policy addresses or contributes to any observed disparities in UTC. With the aforementioned documentation of disparate provision of municipal services, we hypothesized a study of the policy documents shaping UTC in historically racially segregated neighborhoods may illustrate similar inequitable conditions (Heynen et al., 2006). Conducted on a small sample of neighborhoods embedded in municipalities with histories of racial segregation, this analysis is a proof of concept for a mixed methods approach for assessing environmental inequity. Although we focus on UTC within the context of neighboring cities in the southeastern United States, jurisdictions around the world recognize the benefits associated with tree canopy and utilize legislative remedies to protect tree canopy (Konijnendijk, 2003; Schmied and Pillman, 2003). The methodological approach also has applications for investigations of environmental inequity on a range of topics at the intersection of the observable environment and social stratification.

The following sections outline the benefits of urban tree canopy and its potential as an evaluation metric of environmental equity given the history of the environmental justice movement. We then describe the study's methods including the site selection, use of 1-m high resolution imagery to examine UTC, and the content analysis of comprehensive plans and development management ordinances. The paper then presents the findings from an assessment of the UTC for twelve neighborhoods with historic racial segregation and the content analysis of the planning documents governing the installation, preservation, and removal of the UTC. The paper ends with recommendations for how to redesign tree planting and protection policies to produce an overall increase in and more equitable distribution of urban tree canopy.

1.1. Urban tree canopy and environmental justice

The birth of environmental justice movement is often attributed to community organizing and protests of the siting of a hazardous waste landfill in a low income, Black community in Warren County, North Carolina (McGurty, 2000). The event motivated two early studies into the placement of hazardous landfills and subsequent work on the location of hazardous and undesirable land uses in communities of color. The U.S. General Accounting Office's study found three of the four major hazardous landfills within the Environmental Protection Agency's Region IV were sited where Blacks made up the majority of the population (1983) and the United Church of Christ's Commission (UCC) for Racial Justice's demographic profiles of populations living adjacent to hazardous waste facilities throughout the United States found three of every five Black and Hispanic persons lived in communities with unmitigated toxic waste facilities (1987). As the body of literature on environmental inequity grew, some studies found evidence countering a correlation between race and hazardous land uses (Anderton et al., 1994; Bowen et al., 1995). Other researchers attributed the observed correlation between race and locally unwanted land uses (LULUs) such as landfills, sewer treatment plants, and highway corridors to move in by racial minority groups after the installation of LULUs (Oakes et al., 1996). Pastor et al. provide evidence that disproportionate siting of LULUs in existing minority communities was a more significant factor than disproportionate ex-post-facto minority move-in using retroactive temporal geospatial analysis for tract geography over three decades in Los Angeles (2001). A follow-up to the 1987 UCC study concluded commonly attributed confounding variables like income, home ownership and property values were less significant explanatory variables than race alone (Bullard et al., 2007).

Environment equity studies of urban tree canopy focus on the relationships among race/ethnicity andincome at various geographies. The work of Cooper, Liberti, and Asch posits the 1937 Home Owner's Loan Corporation "Redline" maps reflect racial and economic disparity in UTC and suggest the tree-planting operations of Durham County, North Carolina between 2007 and 2014 continued or exacerbated inequality (2016). A census tract level analysis of urban forest within the city of Milwaukee found non-Hispanic White populations were more likely to have more tree canopy compared to non-Hispanic Black and non-White Hispanic populations and concluded racial and ethnic factors interact with the distribution of the urban canopy independent of political and economic factors (Heynen et al., 2006). In a nationwide assessment of heat-risk related land cover (HRRLC)—areas where at least 50% population does not live within UTC and more than 50% half of the ground is impervious surface—Jesdale, Morello-Frosch, and Cushing found that non-Hispanic Blacks were 52% more likely to live in HRRLC areas compared to non-Hispanic Whites (Jesdale et al., 2013). In Tampa, Florida, Landry and Chakraborty's investigation of the distribution of trees within public right–of-way areas concluded that areas with higher percentages of low-income, Black, or renters had lower tree cover within public right of way areas (Landry and Chakraborty, 2009). The literature on the relationship between income and tree canopy suggests a negative relationship. Schwarz et al. emez et al. found that median income was positively correlated with UTC cover within seven major cities in the U.S. (Schwarz et al., 2015). There was a negative correlation between race and UTC cover although the relationship was not observed in a multivariate regression with additional variables like household income, education, and housing age. Watkins and Gerrish's recent meta-analysis of 61 studies investigating the relationship between income and tree canopy concluded there was substantial inequity linked with economic factors.

The prevailing conclusion from these studies is there is evidence that non-White population are more likely to live in areas with lower canopy coverage when compared to White populations and the content and implementation of local policy is linked to UTC. However, the resolution of the data (30 m) and errors of commission and omission in the National Landcover Dataset introduces potential error into the analysis (Wickham et al., 2010) and the use of some larger geographies (i.e., census tracts and block groups) may obscure finer-scale distributions of populations and UTC, which highlights the need for high-resolution assessment of UTC at the neighborhood level. This study uniting a geospatial analysis with evaluation of the policies impacting UTC uses 1-m high resolution land classification maps at the block level on neighborhoods with a racial segregation history and a content analysis. Residential segregation can occur at a sub-block group geography so the aggregation of census blocks along neighborhood boundaries acknowledges the limitations of larger census geographies in capturing neighborhoods. This approach provides an opportunity to examine how residential segregation influences current UTC (Grove et al., 2018).

Our study synthesizes a UTC assessment with an evaluation of current how regulations encourage or hinder the future equitable distribution of UTC. Assessments can provide baseline data for evaluation, inform locality-wide tree canopy goals, and help prioritize tree planting locations (Kimball et al., 2014) and a number of studies examining the linkage between policy and UTC outcomes. Landry and Pu's study of tree canopy in Tampa, Florida found evidence the 1974 tree protection ordinance contributed to more tree canopy at the parcel level for structures developed after its adoption (2010). A similar relationship

between policy and tree canopy was not observed by Heynen and Lindsey who used a policy index along with socio-demographics, urban form, and ecosystem factors to predict tree canopy (2003). They found no statistically significant relationship; however, their policy index only accounted for the presence of a zoning ordinance with provisions around forest management rather than its quality. These studies suggest planning policy can influence UTC, but the influence of quality of comprehensive plans and development management ordinances has not yet been fully investigated.

2. Methods

2.1. Site selection

The historic presence of Black populations in the southeast region of the U.S. and North Carolina's active participation in Jim Crow legislation, state and local laws designed explicitly to create and enforce racial segregation, enabled the identification of racially segregated neighborhoods with timescales congruent with the lifespan of trees. For this study, we selected two neighboring North Carolina municipalities with documented examples of inequitable planning outcomes: Durham and Chapel Hill. The City of Durham engaged in the disintegration of the historically Black Hayti community in the 1970s with the expansion and realignment of Highway 147. The 1970s also marked the promised extension of improved access to basic sewer and water infrastructure in exchange for the siting of a landfill in the Rogers-Eubanks community in Chapel Hill. However, the expansion of services went unfulfilled for decades despite the construction and subsequent expansion of the landfill (Heaney et al., 2011). These historic examples of inequitable provision of municipal services may parallel the inequitable distribution of urban trees as both are dictated by power dynamics and the ability to successfully lobby existing power structures (Heynen et al., 2006).

The intent of the site selection was to choose established neighborhoods that were relatively racially homogenous. Newly built neighborhoods were excluded from the study as greenfield development of a residential neighborhood is often associated with a significant change (e.g. removal) of the UTC. Neighborhoods were selected with specific consideration for the racial/ethnic breakdown of their populations. Within Durham, we used the 1937 Home Owner's Loan Corporation (HOLC) "Redline" maps, urban history texts, and current census data to inform the selection and boundaries of six neighborhoods: 3 historically Black (Crest St., Old East Durham, Walltown) and 3 historically White (Duke Park, Forest Hills, Trinity Park) (Anderson, 2011; Brown, 1985).

Due to its population density at the time, HOLC did not include Chapel Hill among the 239 cities for which it created "Redline" maps. We selected two neighborhoods identified as historically Black neighborhoods during the same era using oral histories and the 1944 map of the "Negro Community": Northside (formerly Pottersfield and Sunset) and Pine Knolls (formerly Knolls development) (The Marion Cheek Jackson Center, 2017). The third community, Rogers-Eubanks Road, is a low income, multi-racial community that lies just outside of the Chapel Hill town limits in the extra-territorial jurisdiction and housed the town's landfill for over forty years. The three historically White neighborhoods (Gimghoul, Coker Hills, and Kings Mill/Morgan Creek) were selected using neighborhood conservation overlay districts, which are designed to protect unique neighborhood characteristics and often utilize historical context to justify their protection. Neighborhood boundaries for both municipalities were collected as GIS shapefiles through the municipality's city's official web portal (City of Durham, 2018a; Town of Chapel Hill, 2018c).

2.2. Urban tree canopy and demographic assessment

For the purpose of this paper, and given the data used, the UTC should be understood to be the canopy when viewed from above. The ability to assess UTC disparity hinges on the availability of data at a spatial resolution appropriate for quantification. Beginning in 2003, the USDA's National Agricultural Imagery Program (NAIP) began to provide 1-meter resolution imagery collected from aircraft on a yearly basis, during the "leaf-on" growing season. Although the primary purpose of the dataset is to assess agricultural crop yields, the spectral and spatial resolution of NAIP allows for assessing UTC. Since 2008, NAIP imagery is packaged with a fourth band—the near-infrared band—in addition to the traditional red, green, and blue bands. The near-infrared wavelength is particularly sensitive to vegetation, making it ideal to use for distinguishing between vegetation and non-vegetation. This spatial resolution of NAIP enables its use in conjunction with U.S. Census block data, as larger (e.g. 30 m resolution) imagery would can contain too few pixels within a single block group for meaningful analysis. At a 1 m scale, the social and political geographies of neighborhoods, which directly ties to historic segregation and public policy, can be used for this assessment.

Four-band (red, green, blue, and near infrared) NAIP imagery was collected for June 19th, 2014 for both Chapel Hill and Durham. The neighborhood boundaries collected previously were used to clip the NAIP tiles, resulting in RGBI images for the extent of each of the 12 neighborhoods. To facilitate supervised classification, training samples were collected in each neighborhood for the following land classes: tree, grass, road/impervious, building, and bare earth. The training samples were evenly distributed throughout the geography of the neighborhood to account for slight variations in atmospheric conditions and lighting.

Maximum likelihood supervised classification was performed to classify all pixels within the neighborhood into the most appropriate class. Not all class types were present in all neighborhoods. For the purposes of analysis, all non-tree classes were combined into a single class. The result was binary raster with all pixels classified as either tree canopy, or non-tree canopy. Fig. 1 provides a side-by side comparison of the RBG imagery and binary classification for two of the neighborhoods to visualize the process. Zonal statistics were used to sum the ratio of tree to non-tree pixels within each block.

Previous studies used census tracts or the block groups embedded within census tracts as the units of analysis (Heynen et al., 2006; Jesdale et al., 2013; Landry and Chakraborty, 2009; Schwarz et al., 2015). The use of blocks, a subgroup of block groups, allowed this study to better approximate neighborhood boundaries. A total of 286 blocks for Chapel Hill and Durham were collected from the 2010 U.S. Census blocks and joined with tabular data for population counts by race (U.S. Census Bureau, 2011). A simple area-based proportional weighting system was used to designate population counts from census geography that only partially overlapped neighborhood boundaries. For example, if 50% of a block group fell within a neighborhood then 50% of the population count for a particular race/ethnic category of that block group was assigned to the overall neighborhood counts. The non-White population was calculated using the following equation: Percentage non-White = 1-(non-Hispanic White population/total population).Georeferenced zoning districts were collected from the Chapel Hill and Durham GIS portal (City of Durham, 2018a; Town of Chapel Hill, 2018c). Zoning districts were selected and clipped out using the neighborhood boundaries to export base zoning districts by neighborhood.

A spatial autoregressive model (generalized spatial two stage least squares regression) was run in STATA 15.0 using block as the unit of analysis. The dependent variable was UTC coverage – calculated as a ratio of area covered by UTC and the total size of the block. Right-of-way was calculated as a ratio of the area of municipally owned right-of-way within the block to the total area of the block. Non-residential zoning determinations were made using a binary calculation. If a zone overlapped any part of the block geography it was assigned a value of 1. The percentage of UTC was regressed on percentage non-White,

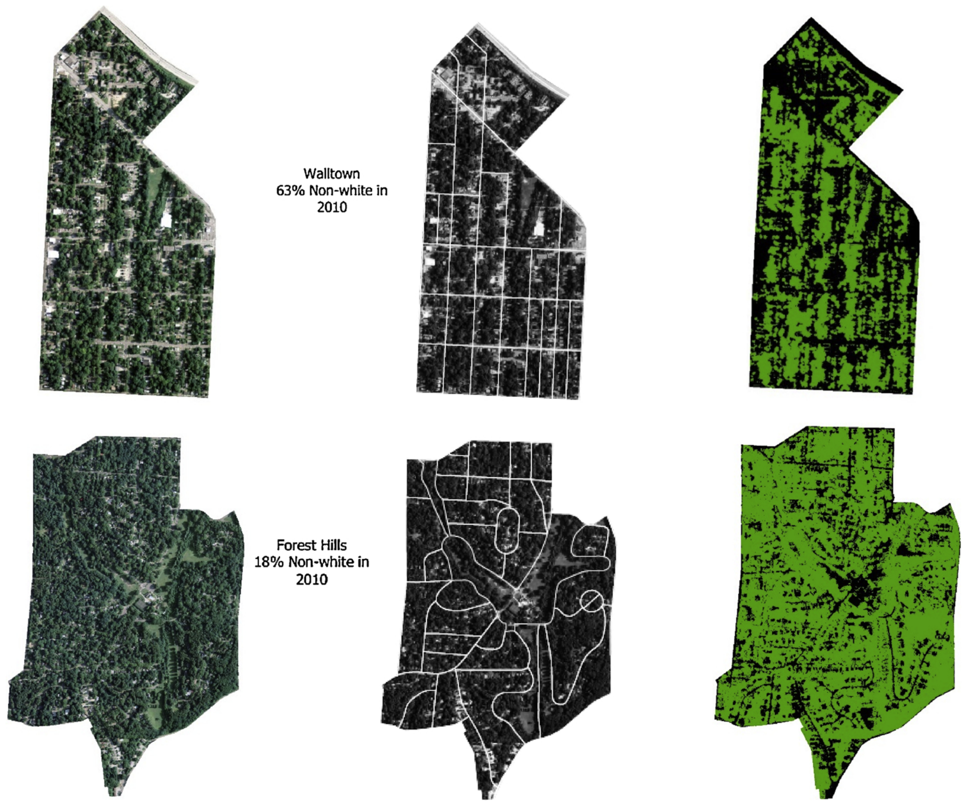

Fig. 1. RGB imagery, Census block delineation, and binary urban tree canopy classification rasters for the Forest Hills and Walltown neighborhoods in Durham, NC. Walltown was 63% non-White in 2010 with 37% UTC coverage. Forest Hills was 18% non-White in 2010 with a high 57% UTC coverage.

percentage of the block's area designated as right-of-way, and binary variables of whether a block contained residential or non-residential zoning districts, and whether the neighborhood was located in Durham.

2.3. Comprehensive plan and development management ordinance evaluation

The provision and maintenance of UTC is the responsibility of multiple parties (Bardekjian, 2016; Donovan and Butry, 2010; Watkins et al., 2017). However, the proximity and distribution of urban tree canopy and its attending ecosystem services can be both direct and indirect results of municipal land use decisions (Arnold, 2007). Plans and ordinances most directly influence land use decision-making through the development and redevelopment process and there is research linking the quality of plans with better outcomes (Berke et al., 2006; Brody and Highfield, 2005; Burby et al., 1997). In a meta-analysis of plan quality evaluation, Berke and Godschalk identified principles that should serve as evaluation criteria for the quality of a plan: goals, fact base, policies, implementation, monitoring and evaluation criteria, and overall internal consistency (2009). First, a strong fact base begins with comprehensive assessment of the UTC within the municipality, or call for its creation if such an assessment has not been performed. They consistently found that the weakest element of plans are a lack of substantial fact-base (2009). Next, goals related to the UTC should strive for the enhancement or increase of UTC wherever feasible and draw upon the fact base to identify and require enhancement for areas that have lower than average amounts of coverage. Finally, policies related to the UTC should be specific, measurable, and implementable.

Durham and Chapel Hill are geographically close, but provide variability in planning documents as they are distinct jurisdictions. Comprehensive plans and development management ordinances were downloaded from both municipal websites. The comprehensive plans were first reviewed for sections containing variations of the following terms and phrases: tree canopy, trees, and urban forestry. Then, these sections were coded as including goal language, containing facts about UTC, or describing policies with direct influence on UTC. Finally, the comprehensive plan assessment protocol focused on 1) the specificity of goals concerning UTC, 2) the level of detail describing existing UTC within the community, and 3) if these data were used to inform regulations and policies and the types of policies outlined in the plan.

We extended the application of plan quality principles to ordinances with a focus on the goals, fact base, and policies contained in these planning documents. The assessment protocol for the development management ordinance began with a review of the purpose statement with the listed rationale for the creation of the ordinance. These statements were assessed for the presence of rationale related to racial or socioeconomic equity, UHI, and neighborhood composition. Additionally, differentiation between the existence of a goal or element and detailed reasoning behind the creation of that goal was considered. The following questions were posed to each development ordinance:

Does the ordinance:

- Establish a base of rationale for preservation or enhancement of UTC?
- Have a goal related to UTC coverage? Is it a detailed goal?
- Mention or recognize potential UTC disparities within the Town or City?
- Discern between UTC on public or private lands, including right-of-way?
- Include specific requirements or considerations for UTC within neighborhoods?
- Include regulations that are designed to increase UTC from its pre-development status?
- Have procedures for the replacement of trees that the ordinance requires to be removed?

Table 1
Mean Percentage of non-White, Average UTC coverage and Zoning Districts by Block.

Neighborhood	# of Blocks	Mean % non-White (2010)	Range (SD)	% of UTC (2014)	Range (SD)	Mean % ROW	Range (SD)	Zoning Districts
Old East Durham	50	88.3	12.5–100 (14.7)	51.4	17.1–74.2 (12.5)	20.5	11.6–44.2 (5.8)	**Residential:** RU-5(2), RS-M **Nonresidential:** CN, OI, IL
Crest Street	2	89.7	88.2–91.1 (2.0)	45.7	43.6–47.8 (3.0)	19.8	17.8–21.7 (2.7)	**Residential:** RU-M, RU-5(2) **Nonresidential:** CG
Walltown	34	65.4	0–91.5 (20.6)	48.8	15.7–64.6 (10.9)	28.7	19.8–40.9 (3.7)	**Residential:** RU-5, RU-5(2), RS-M **Nonresidential:** CN, OI
Duke Park	38	45.8	1–100 (29.2)	73.6	43.3–88.7 (11.3)	26.7	17.1–46.7 (6.1)	**Residential:** RS-8, RS-M, RU-5, RU-5(2), RU-M. **Nonresidential:** CN, IL
Forest Hills	35	21.3	0–80 (20.1)	75.8	54.6–90.6 (7.8)	22.5	12.3–57.6 (9.3)	**Residential:** RS-8, RS-10, RS-20, RU-5, RU-5(2), RS-M
Trinity Park	62	24.8	0–95.7 (23.1)	65.5	14.1–89.3 (14.6)	25.2	14.3–39.4 (6.1)	**Residential:** RS-8, RU-5, RU-5(2), RS-M, RU-M **Nonresidential:** CN, OI **Planned:** DD-S2
Pine Knolls	6	57.0	36.7–80.5 (14.6)	68.0	55.2–75.8 (7.4)	16.2	10.4–26.2 (5.6)	**Residential:** R-2, R-3, R-4 **Overlay:** Neighborhood Conservation
Northside	26	40.3	0–87.0 (26.4)	71.6	43.6–100 (15.7)	12.7	0–41.9 (8.2)	**Residential:** R-3, R-4, R-SS-C, **Nonresidential:** OI-1, OI-3 **Planned:** TC-2, TC-2-C **Overlay:** Neighborhood Conservation
Rogers-Eubanks	6	30.7	13.3–78.8 (24.5)	89.2	73.8–99.2 (9.3)	4.7	0–10.1 (4.0)	**Residential:** R-1, R-5-C
Kings Mill / Morgan Creek	14	20.8	0–80.0 (25.7)	88.0	74.2–92.3 (5.0)	14.3	0–26.2 (6.9)	**Residential:** R-1 **Overlay:** Neighborhood Conservation
Coker Hills	9	14.2	0–32.0 (10.0)	91.4	87.8–94.2 (2.3)	18.3	14.6–22.2 (2.3)	**Residential:** R-1 **Overlay:** Neighborhood Conservation
Gimghoul	4	5.6	0–18.8 (9.0)	70.6	63.5–89.1 (12.4)	12.7	6.3–15.1 (4.3)	**Residential:** R-1 **Overlay:** Historic District

Table 2
Predicting Urban Tree Canopy using Generalized Spatial Two Stage Least Squares Regression.

Variable	Coefficient	Standard Error	z	p-value
% Non-White Population (2010)	−0.202	0.022	−9.09	0.000
% Right of Way (ROW)	−0.376	0.100	−3.75	0.000
Presence of Nonresidential Zoning	−0.145	0.018	−8.18	0.000
Location in Durham	−0.070	0.020	−3.42	0.001
Intercept	0.923	0.021	43.55	0.000

Significant codes: *p-values ≤ 0.1, ** p-values ≤ 0.05, *** p-values ≤ 0.001.
n = 286.
Wald χ^2 (4) = 312.69.
Prob > chi^2 = 0.000.
Pseudo R-Squared = 0.5223.

3. Results

3.1. Urban tree canopy analysis

A USDA Forest Service survey of major U.S. cities found an overall average of just 27.1% UTC coverage (2017). Compared to national averages, all selected neighborhoods within Durham and Chapel Hill contain relatively high UTC coverage. Table 1 summarizes the mean percentage non-White population, mean UTC coverage, and zoning districts by block within each of the study neighborhoods. It should be noted that the mean percentage of the Rogers-Eubanks Road neighborhood is 30.7%, but the census block containing the landfill is 79% non-White with a UTC of 74% while the other three census blocks were predominately White with higher UTC values (13% non-White, 91% UTC; 26% non-White, 83% UTC, and 11% non-White, 93% UTC). A Wilcoxon-Mann-Whitney test found the historically White neighborhoods communities has statistically significantly more right-of-way in each block. Two historically Black neighborhoods account for 62% of the blocks with nonresidential zoning.

All coefficients were statistically significant at the 0.001 level. A coefficient of −0.202 for non-White populations indicating that increased representation of non-White populations is correlated with reduced UTC coverage. For every one percentage point increase in UTC, the percentage of non-White population decreased by 0.202 controlling for other variables. The presence of right-of-way was also negatively correlated with UTC coverage and was a statistically significant variable in the regression. For every one percentage point increase in UTC, the percentage of the parcel that was the right-of way decreased 0.376 controlling for other variables. In other words, the amount of UTC increased as either parcel size increased or right-of-way decreased controlling for all other variables. The presence of nonresidential zones were also negatively correlated with UTC coverage such that the location of a nonresidential zoning district within a block decreased UTC by 0.145 controlling for other variables. Finally, the presence of a block in Durham was negatively associated with UTC (−0.070), but this variable did not achieve traditional levels of statistical significance. Table 2 includes the results of a generalized spatial two stage least squares cross-section regression of UTC on percentage of non-White population, percentage of ROW, presence of non-residential zoning, and location in Durham using an inverse distance weighting matrix.

3.2. Plan and ordinance assessment

Chapel Hill's Comprehensive Plan includes limited mention of UTC. The "extensive tree canopy" is noted as a tangible asset for the community and protecting existing tree canopy is listed as a "connecting quality" among neighborhoods within Chapel Hill (2012: 19). However,

Table 3
Development Management Ordinance Analysis by Municipality.

Analysis Question - Does the ordinance or plan…	Chapel Hill	Durham
Establish a base of rationale for preservation or enhancement of UTC?	Yes. To "preserve, maintain, and increase tree canopy to protect the public health, safety, and welfare and enhance quality of life"	Yes. Multiple benefits are listed as benefits of the UTC.
Have a goal related to UTC coverage? Is it a detailed goal?	Yes. "[UTC should be maintained] to the maximum extent practical." Vague language allows for significant removal of UTC.	No.
Mention or recognize potential UTC disparities within the Town or City?	No.	No.
Discern between UTC on public or private lands, including right-of-way?	Yes. Most regulations triggered by development. Modification of these requirements are allowed when "public purposes are met, and canopy removal supports other goals of the town." In some cases, right-of-way is explicitly excluded from the calculation for UTC coverage on a development site.	Yes. The ordinance requires one retained or planted tree for every 40 feet of property frontage on a public right-of-way for development projects greater than 4 acres.
Include specific requirements or considerations for UTC within neighborhoods?	Yes. Only via community-generated proposals for designation as "Neighborhood Conservation District."	Yes. Only via community-generated proposals designation as "Neighborhood Protection Overlay" zoning district.
Include regulations that are designed to proactively increase UTC from its current status?	No.	Partially. The ordinance differentiates between *preserved* and *total* tree coverage in development
Have procedures for the replacement of trees that the ordinance requires to be removed?	No.	No.

maintaining or increasing the tree canopy is not listed as a goal and there are no policies or objectives that are directly associated with tree canopy.

Durham's Comprehensive Plan also contains limited mention of UTC. Within the Conservation and Environment chapter, the only stated policy related to UTC states that the City-County Planning Department shall "research and propose development regulations and/or programs to increase and target" UTC (City of Durham, 2017: 7–5). This policy is nested within the objective of preserving and enhancing air quality, and the rationale for increasing or preserving UTC is consequentially referenced in terms of the air quality benefits of trees. There are not data describing current UTC or any goals explicitly linked to UTC.

The development ordinances represent a tool that can be used to help manage UTC and operate as the practical extension of the vision outlined in the comprehensive plan. Guidance and requirements given by the ordinances directly contribute to the built and natural environment, and both Chapel Hill and Durham have sections within their development ordinances that regulate the provision, protection, and enhancement of the tree canopy. Table 3 summarizes the development management ordinance analysis.

Establish a base of rationale for preservation or enhancement of UTC? The general purpose of the Chapel Hill provision is to "preserve, maintain, and increase tree canopy to protect the public health, safety, and welfare and enhance quality of life in Chapel Hill" (2018a: 5.7.1(b)). While similar in the nature, the Durham provision includes a larger number of preservation rationale (2018b: 8.3.1& 9.1.1). However, in both cases, the rationale is simply listed with no further explanation as to how exactly elements of the provision address specific rationale.

Have a goal related to UTC coverage? Is it a detailed goal? Chapel Hill states that UTC coverage should be maintained to the "maximum extent practical" over all land uses within the town (Town of Chapel Hill, 2018b). It is notable that the phrase "practical" is used, as it allows for modifications of the UTC coverage in cases where it is deemed to be impractical to preserve it. There is no further detail beyond the single sentence that outlines preservation when practical. Minimum requirements for UTC only apply to development applications. There is no requirement for consideration of the UTC outside the bounds of the developing parcel. Town-wide changes in UTC over time are not explicitly regulated. The Durham ordinance contains no goals with respect to UTC coverage. Notably, neither municipalities have an overall goal for UTC coverage within their jurisdiction.

Mention or recognize potential UTC disparities? Neither Chapel Hill nor Durham either explicitly or implicitly acknowledge the presence or possibility of disparity in UTC coverage within either their overall jurisdiction, or within neighborhoods. The lack of a comprehensive assessment of UTC for either municipalities (part of their fact-base) makes recognition of such a disparity difficult.

Discern between UTC on public or private lands, including right-of-way? The Chapel Hill minimum canopy coverage regulation is not a requirement for the total UTC within these land uses, but rather applies specifically to development applications (Town of Chapel Hill, 2018b). The Chapel Hill Tree Protection Ordinance states that 30% minimum canopy coverage is to be maintained for multi-family residential and commercial and 40% minimum canopy for institutional and mixed use.

The Chapel Hill ordinance references the possibility that UTC for a site, even prior to development, may already be below the allowed threshold for that land use. Compliance with the minimum coverage standards "shall" be established, but the mitigation mechanisms to establish compliance include actions that may still reduce the overall UTC (Town of Chapel Hill, 2018b). In the case where the existing tree canopy is less than the minimum standard, the regulation allows for trees in the right-of-way to be counted toward the standard calculation, even though the initial calculation for minimum canopy coverage explicitly excludes right-of-way. Additionally, trees within parking lot shading areas and town buffers may be counted toward the minimum coverage, even though they are not counted in the original calculation (Town of Chapel Hill, 2018b).

The ordinance says that one replacement tree per 500 square feet of UTC deficit shall be planted. Even assuming the largest tree possible, this ratio will fall well below the minimum standards for the 500 square foot area. Overall, when the UTC standard is not met, the ordinance allows a number of mechanisms that give discretion to reduce the strictness of the original standard. Furthermore, the minimum canopy coverage standards for these land uses explicitly exclude public right-of-way, and only apply to the zoning parcel boundary. Trees coverage in public right-of-way is not assigned a minimum canopy coverage.

Like the Chapel Hill ordinance, the Durham Unified Development Ordinance distinguishes between residential and non-residential

development for its requirements related to UTC, and does not provide or require an overall UTC coverage for the city, or within smaller geographies such as zoning districts or neighborhoods. In contrast to the Chapel Hill ordinance, the Durham Unified Development Ordinance further differentiates between *preserved* and *total* tree coverage area (City of Durham, 2018c). Regardless, these thresholds for Durham regulations only apply to development of four acres or more. Smaller developments, such as single-family homes in residential zoning district, are not subject to these regulations.

Include specific requirements or considerations for UTC within neighborhoods? Chapel Hill allows areas that are designated as Neighborhood Conservation Districts to request modifications of the land-use-based UTC requirements (Town of Chapel Hill, 2018b). Northside, Kings Mill, and Pine Knolls have Neighborhood Conservation District designation while Gimghoul has a historic district designation. Rogers-Eubanks and Coker Hills do not have any additional designation. Durham includes all six selected neighborhoods as neighborhood designations, but the ordinance does not include any special requirements or elements that relate to those geographies. However, an overlay zoning district known as a “neighborhood protection overlay” may require a specific amount of tree coverage for a neighborhood within the city.

Include regulations that are designed to increase UTC from its pre-development status? Both ordinances have requirements to preserve a variable percentage of a parcel’s UTC coverage in the case of development (City of Durham, 2018c; Town of Chapel Hill, 2018b). However, these values range from 10 to 40%, meaning that development of forested parcels will always result in less UTC coverage after development. In all cases, the ordinances minimize reduction of UTC, rather than calling or requiring for its increase.

Have procedures for the replacement of trees that the ordinance requires to be removed? Both ordinances have strong language requiring the removal of trees that pose a risk to property or human health (City of Durham, 2018c; Town of Chapel Hill, 2018b). Risk to both city and private property are included as valid justification for the removal of trees, and neither ordinance requires the replacement of trees removed for this reason. Both Durham and Chapel Hill tree protection ordinances define varying canopy coverage requirements based on zoning district and/or land use (City of Durham, 2018c; Town of Chapel Hill, 2018b). Thus, the zoning districts present within each neighborhood directly influence the UTC coverage requirements. Per the ordinances, non-residential uses have lower minimum canopy coverage requirements, and areas with this zoning designation likely have higher impervious surface coverage, lower tree canopy coverage, and more noxious uses in terms of air-quality-reducing emissions from commercial and industrial facilities and associated supporting infrastructure like trucks – when compared to areas completed zoned as residential. Although the Durham neighborhoods, by area, generally contained a majority of residential zones, there was a significant amount of office/institutional, light industrial, and non-residential commercial neighborhood zones in the historically Black neighborhoods. For example, 100% of the area within Forest Hills contains residential zoning districts. In contrast, only 74% of Old East Durham contains residential zoning districts with heavy industrial zoning districts make up 14% of the land area.

The Chapel Hill Zoning Ordinance contains significantly fewer zoning districts compared to Durham. The majority of neighborhoods exclusively contained residential zoning district with the exception of the Northside neighborhood, which contained office/institutional and school zoning districts. It should be noted that a portion of the Chapel Hill Rogers-Eubanks neighborhood falls outside of the town extra-territorial jurisdictional boundaries, and thus does not have municipal zoning districts.

4. Discussion

The results of the spatial autoregressive model indicate that the presence of non-White populations is negatively correlated with UTC coverage in the 12 study neighborhoods, which is in line with previous studies that found a negative relationship between race and UTC (Heynen et al., 2006; Jesdale et al., 2013; Landry and Chakraborty, 2009; Schwarz et al., 2015). The negative relationship between UTC and the location of a neighborhood in Durham may reflect the denser urban form of the city. The percentage of public right-of-way was statistically significantly higher in the historically White neighborhoods and negatively associated with UTC. This observation may reflect historic differential provision of public infrastructure such as roads, sidewalks, and other physical infrastructure associated with transportation in non-White communities. This observation also highlights an opportunity as a municipality can exert more control over rights-of way compared to private land. Regulations requiring more UTC in the right-of-way may provide an effective strategy to counteract disparity in UTC across neighborhood geographies (Cooper et al., 2016).

Both the qualitative and quantitative analysis of the zoning districts indicate that non-residential zoning districts are more prevalent in non-White neighborhoods. The relationship between nonresidential zoning was largely driven by the Durham neighborhoods of Old East Durham and Walltown which account for 62% of the blocks with some non-residential zoning. However, there are undesirable uses in or adjacent to two of the study neighborhoods in Chapel Hill that were not detected with the nonresidential zoning analysis. As stated before, there is a landfill located within the Rogers-Eubanks neighborhood and there is a cogeneration energy plant located adjacent to Pine Knolls. These findings are a reminder of the role that special use permits and conditional zoning can play in shaping the built environment that are not present in zoning designations.

There are limitations to the geospatial analysis. A supervised classification process using NAIP imagery exclusively relies on two-dimensional data that does not differentiate between tree types, nor does it assess the volume or health of existing trees. Future analyses could introduce full-cloud point classified LIDAR datasets, which can identify and classify different tree species providing a more accurate assessment of the volume of an urban tree canopy and its overall health.

While municipal governments are not the only entities affecting UTC, Chapel Hill and Durham’s both missed opportunities to protect and enhance UTC. Neither Durham nor Chapel Hill have a municipality-wide minimum canopy coverage requirement, and the standards in place have varying applicability based on land uses with explicit allowances for modifications or reduction. Tree coverage standards for both municipalities generally only triggered for new development, and both ordinances give significant leeway in a developer’s ability to modify (reduce) the UTC coverage requirement, in cases where minimum thresholds of UTC are required at all. In Durham, minimum canopy coverage percentages by zoning district only apply to projects of four acres or larger. Less than one percent of all parcels within the Durham neighborhoods studied are four acres or more. Upon development, these parcels could be reduced to as little as 0% UTC excluding the few trees required at the interface of the parcel and the right-of-way or by special overlay zoning district.

As the ordinances only applies to new development applications, the historical antecedents may influence the UTC are not directly addressed. If a neighborhood contains less canopy coverage, there are no mechanisms to increase that coverage. A neighborhood that is largely built out, not undergoing significant development, or under protections that may inhibit development will, at best, maintain its existing UTC. Further, as trees die off or are removed, the UTC will decrease over time. Both ordinances define conditions where a tree must be removed if it poses a threat to human health or public infrastructure, but neither ordinance contains provisions nor requirements for the replacement of those trees. The decreased percentage of canopy sometimes becomes the baseline under which new development must comply, compounding the reduction of UTC.

UTC for development at the scales typical for a residential neighborhood are largely unregulated with some exceptions for overlay

zoning districts. Both ordinances and plan frameworks allow for specific neighborhoods to lobby for the adoption of higher UTC coverage standards specifically for their geography. This policy making process allow for resident input into the UTC regulation process, but also provides a mechanism for disparate protection of UTC coverage. Tying ordinance content to the resources available to community and their ability to effectively lobby the municipality to adopt higher standards for their neighborhoods can exacerbate disparities observed in historically marginalized communities.

Low-income communities often consist of smaller parcels. The explicit allowance of right-of-way to be removed from the tree canopy calculation means that smaller parcels, in absolute terms, are allowed to have less canopy coverage as a function of their total area. The Durham Unified Development Ordinance and the Town of Chapel Hill ordinance both allow less tree coverage within non-residential zoning districts when compared to residential districts. Majority-minority neighborhoods are more likely to having zoning that allows for nonresidential uses near residential uses (Arnold, 2007). Thus, the presence of a non-residential land use within a neighborhood means that the threshold for minimum canopy coverage is lower than a neighborhood comprised entirely of residential uses, reinforcing racialized differences in UTC.

Neither jurisdiction defines a monitoring or assessment system to track the effectiveness of UTC policies. Without goals for minimum UTC coverage requirement and policies to enhance UTC through tree planting and replacement, there are few strategies in place to maintain UTC and remediate environmental inequities and no clear indicators to track progress. We recommend utilizing the plan quality principles used as the basis for our analysis to shape a course of action for Durham, Chapel Hill, and other jurisdictions striving to protect and improve their UTC.

- Fact Base: Perform a comprehensive UTC coverage assessment across the entire municipality (See the San Francisco Urban Forest Plan (San Francisco Planning Department, 2014).
- Goals: Adopt a municipality-wide UTC coverage goal in the comprehensive plan, against which all development decisions relating to UTC would be weighed against (See Baltimore, MD goal to reach 40% UTC coverage by 2037 (TreeBaltimore, 2017). Building on the factual basis of the UTC assessment, planning and ordinance regulations would have a standard to balance the pace of development with an overarching UTC minimum.
- Goals: Adopt parcel-level and neighborhood UTC coverage minimums to supplement the existing zoning district requirements (See Watershed Forestry Resource Guide on augmenting UTC ordinances (Watershed Forestry, 2017)) and the city of Philadelphia's 30% canopy goal for every neighborhood-. Neighborhood-scale UTC goal in the comprehensive plan provide an opportunity to define and remediate uneven geographic distribution UTC.
- Policy Framework: Increase minimum UTC coverage requirements for residential land uses and zoning districts
- Policy Framework: Eliminate or reduce allowances for leeway in the UTC coverage requirements, such as inclusion variable inclusion of the ROW in UTC coverage calculations
- Policy Framework: Adopt a 1:1 ratio of tree replacement for trees that are required to be removed by the development ordinance.

5. Conclusion

The intentional preservation or placement of trees has a long term effect on UTC, human and ecosystem health, and community valuation, and, due to their long lifespan and fragile young years, long-range planning for canopy coverage and well-being is essential (USDA Forest Service, 2017). Our geospatial assessment of UTC within historically racially segregated neighborhoods replicated disparities documented in other research and the qualitative assessment indicated existing policies are unlikely to maintain or increase existing UTC let alone address differences between neighborhoods. While both municipalities recognize the linkage between tree canopy and desirable health and economic outcomes, there is a need to assess UTC at the neighborhood level, revise and create goals at multiple scales to enhance rather than simply maintain UTC, and investigate and implement strategies to remediate environmental inequities tied to race. The conventional loss of urban trees coupled with the looming threat of increased temperature and drought present a serious threat to UTC opens up the possibility that majority-minority communities will bear higher economic and social costs. Although multiple stakeholders participate in the creation and maintenance of the UTC, municipal action to enhance UTC through revisions and additions to comprehensive plans and development management ordinances illustrates the fundamental appeal of planning: the opportunity to take action in the short term to shape future outcomes.

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